



NASA Langley Tasks



Select Integrated Low Noise Technologies (SILNT)

and

Revolutionary Approaches to Produce Innovative Designs (RAPID)

Michael E. Watts
Langley Rotorcraft Program Manager



SILNT Project Overview



Project Goal

Develop the technology to reduce rotorcraft interior and exterior noise, consistent with NASA Goals: Reduce the perceived noise of future aircraft by a factor of two by 2007 and by a factor of four by 2022. Double the aviation system capacity by 2007 and triple it by 2022.

Objectives

1. Develop low-noise drive systems
2. Develop low-noise & vibration rotor systems
3. Develop low-noise operations

Benefit

Rotorcraft to meet community and passenger acceptance standards for environmental noise and ride quality.

Partners

Bell, Boeing, Sikorsky, US Army, DARPA, FAA

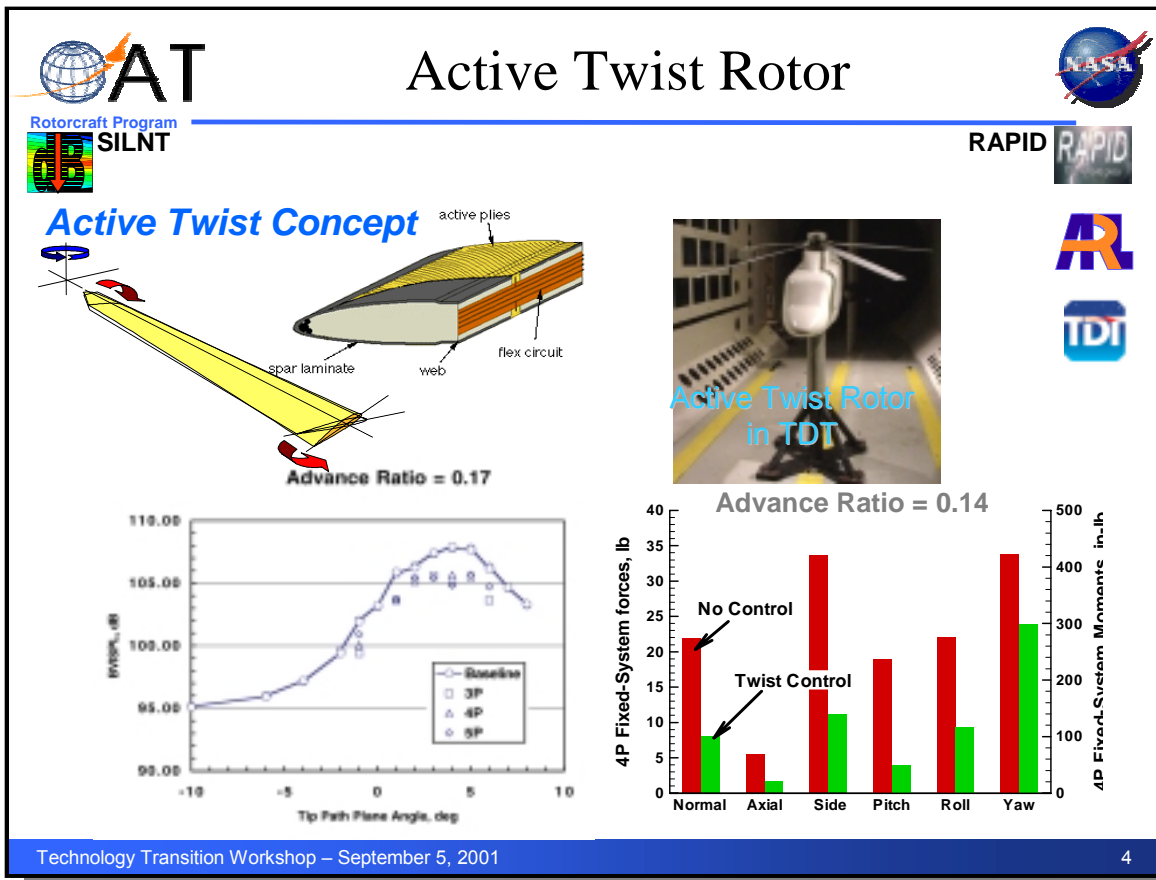




Technologies/Tasks Presented



- RAPID
 - Active Twist Rotor (ATR, Joint with SILNT)
 - Projection Moire Interferometry (PMI)
 - Wing Rotor Aeroelastic Testing System (WRATS)
 - Stringer Pull-off Prediction
- SILNT
 - Low Noise Planform
 - Modulated Blade Spacing
 - Development of Noise Abatement Procedures
 - TiltRotor Aeroacoustic Code (TRAC)
 - Rotorcraft Aeroacoustic System Prediction (RASP)
 - Advanced Rotor Aeroacoustic Modeling (ARAM)
 - Rotorcraft Noise Model (RNM)
 - DGPS Tracking and Guidance System
 - HART II Test



Active Twist Rotor Control for Noise and Vibration Reduction

Matt Wilbur, Earl R. Booth, Larry Becker, Paul Mirick, Bill Yeager, and Chester Langston

Relevant Milestone: Assess the feasibility of multiple radical rotor noise and vibration reduction concepts. (SILNT #2 due Sep 00)

Shown: Active Twist Rotor concept. Blades installed in the Transonics Dynamics Tunnel. Test results for simultaneous fixed-system load reduction obtained using active twist control for a typical 1g forward flight case at an advance ratio of 0.14 and shaft angle-of-attack of -1 degree. A comparison of BVI noise levels at advance ratio = 0.17 with and without ATR as a function of tip path plane angle is also shown.

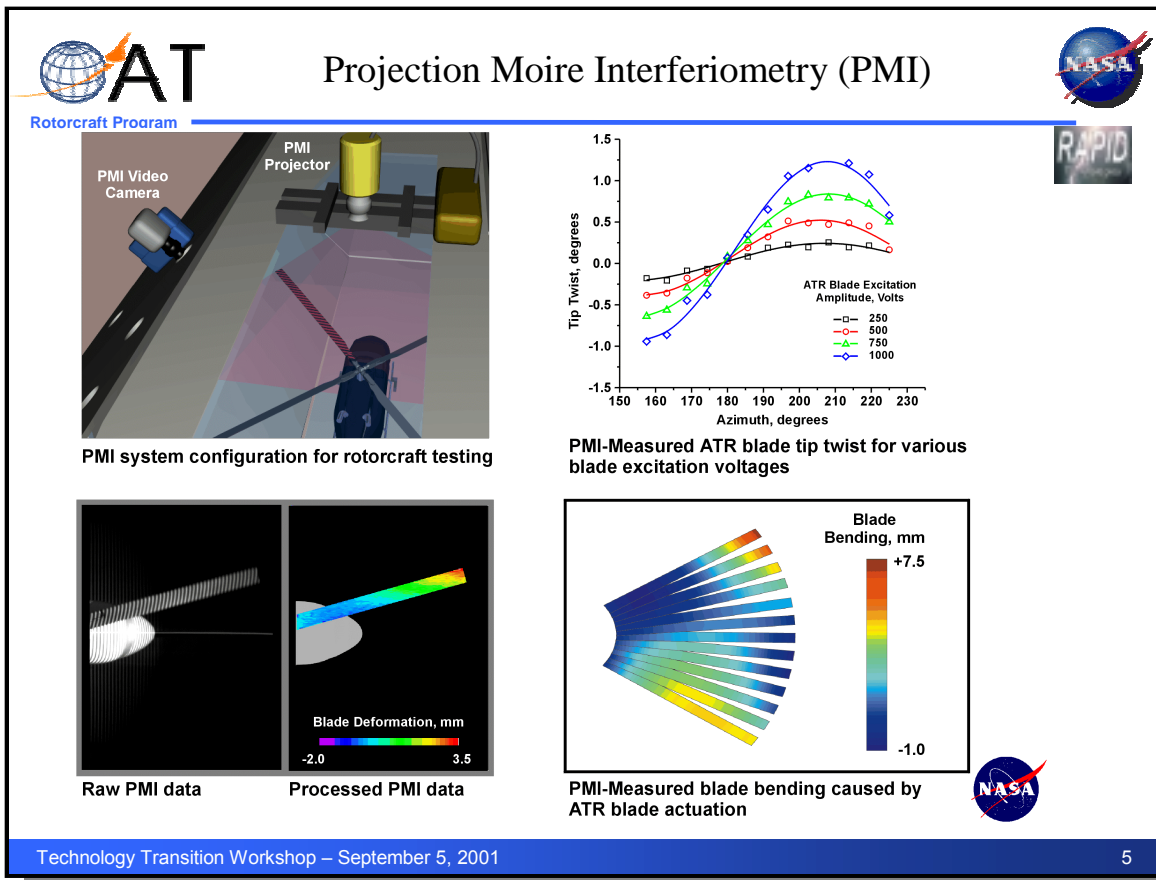
Accomplishment/Relationship to Milestone and ETO:

- New method for rotor noise and vibration reduction using active twist blade control. Contributes to milestone completion.
- Active blade twist was imposed on a rectangular planform, NACA 0012, linear twist blade set. Resulting changes in rotor performance, vibration and acoustic characteristics were compared with the baseline blade (no active twist) case, in a four-week test in the TDT.
- Using an open-loop control system, vibration reductions of 60% to 100% have been demonstrated for all 4P fixed-system load components with exception of yawing moment. General trend suggests that simultaneous reduction of most fixed-system loads, regardless of flight condition, is possible.
- Noise reduction in conditions dominated by Blade-Vortex Interaction (BVI) noise was comparable to noise reduction provided by Higher Harmonic Control (HHC). As shown, in the region of highest BVI noise levels for this advance ratio, ATR reduced the noise up to about 3 dB.
- On July 18 and 19, Matt Wilbur, an Army employee in the Aeroelasticity Branch, traveled with Mr. Dan Hoad, Chief of the Army Loads and Dynamics Division at Langley, to Sikorsky Aircraft in Stratford, CT, to discuss the results of last year's Active Twist Rotor test in the Transonic Dynamics Tunnel. Approximately 15 Sikorsky engineers attended the briefing, which was well-received and generated numerous discussions and comments regarding the potential for active twist rotor systems to minimize vibratory loads in rotorcraft.
- A follow-on trip was made on July 23 to present the material to Boeing Helicopters in Philadelphia, PA. A similar, positive reaction was displayed by Boeing.

Future Plans/Opportunities:

- It is intended to test the existing ATR blade set using three closed loop control systems in FY02. These algorithms include testin a Classic closed loop controller, Generalized predictive controller and Neural generalized predictive controller.
- Extensions of this research would be to build the blade set using MFC actuators to increase control authority and retest with the closed loop controllers. Additional trips are being planned to present the results to Bell Helicopter and Boeing-Mesa, and other Army organizations at NASA Ames Research Center and Huntsville, AL.

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Projection Moire Interferometry (PMI) for Blade Deformation Measurements during Active Twist Rotor (ATR) Testing

Gary Fleming, Hector Soto, and Bruce South

Relevant Milestone: DEAR 5: Rotor/Wake Load Model, accurate model to predict blade loading, including rotor wake interaction, rotor maneuver near limits of rotor envelope.

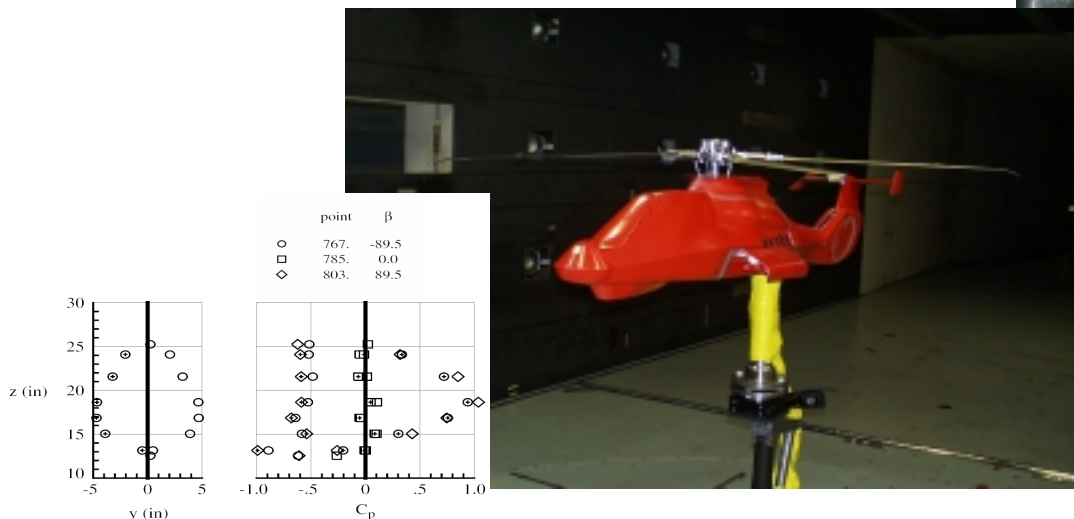
Shown: A schematic of the PMI system configuration for rotorcraft testing is shown along with PMI-measured blade deformation data acquired during the ATR test. The images show full-field raw and processed PMI data for a single blade at 195 degrees azimuth. Additional plots showing spanwise blade bending and azimuthally-dependent tip twist are provided.

Accomplishment/Relationship to Milestone and Goal:

- A significant component of this DEAR milestone is the development of advanced test techniques for blade deflections. PMI is a non-contacting optical technique for measuring structural deformation which can be applied to rotorcraft testing.
- The PMI technique as developed under DEAR was applied to the SILNT ATR test conducted in the LaRC Transonic Dynamics Tunnel to provide (a) blade deformation data to ATR researchers, and (b) additional development opportunities for the PMI technique.
- PMI was used to obtain full-field ATR blade deformation measurements over the 160 - 220 degree azimuth range for numerous blade actuation and flight conditions.
- The full-field PMI measurements have been reduced to provide azimuthally-dependent spanwise blade bending, twist, and tip twist data

Plans: The PMI technique will continue to be developed for rotorcraft blade deformation measurements.

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Comanche Lateral Pressure Distribution at
X=17 in.
Port side is centered symbol

Interactional Aerodynamics

Kevin Noonan

Relevant Milestone: Rotor/Airframe Interaction Model (RAPID #3 due Jul 03)

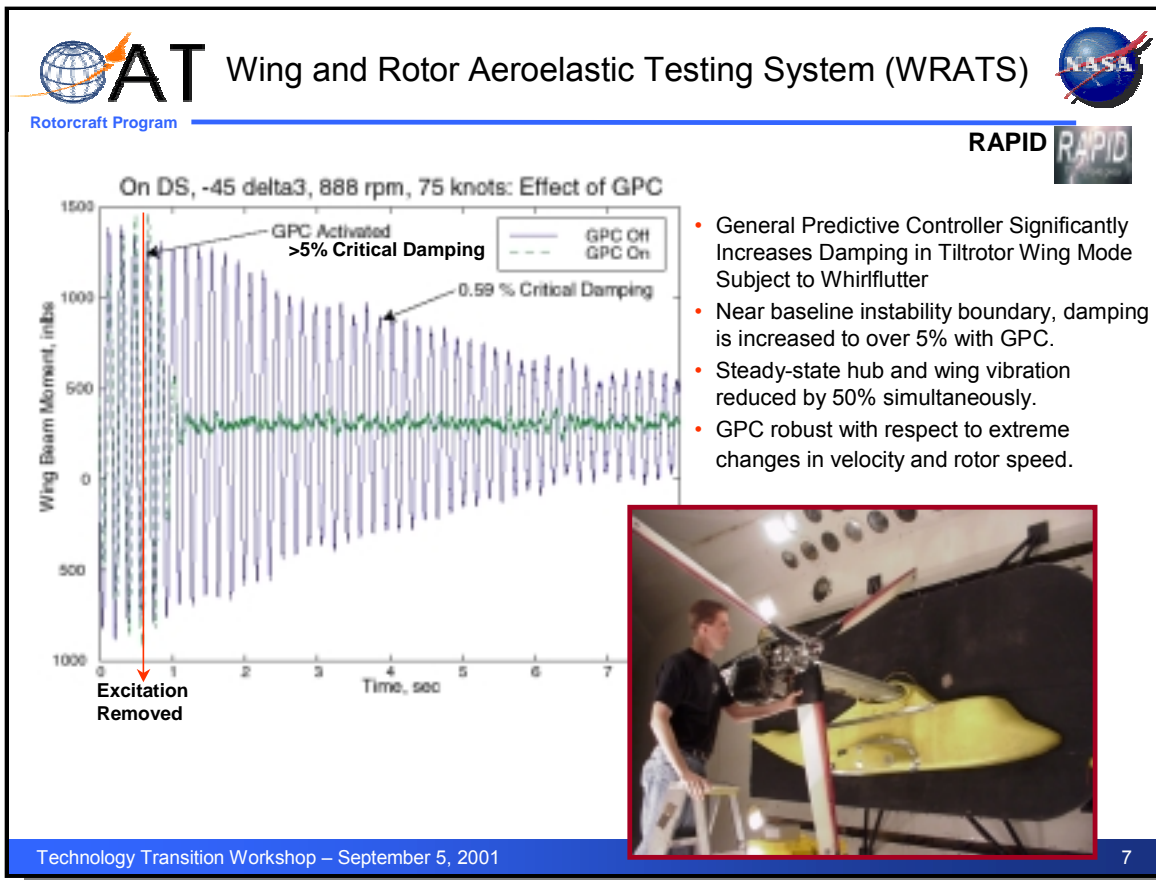
Shown: 1) 15%-scale Comanche model in the 14x22-Foot Subsonic Wind Tunnel tested in FY01. 2) Static pressure distributions at one fuselage cross section (longitudinal station=17 in.) at high sideslip angles without the presence of the rotor flow.

Accomplishment / Relationship to Milestone and ETO:

- Extensive fuselage static pressure measurements were made on the 15%-scale Comanche model during the FY01 entry in the Langley 14x22-Foot Subsonic Wind Tunnel.
- This work is essential to understand and model the complicated flow field around a helicopter. This research will enable rapid design and evaluation of innovative vertical lift configurations for the next generation public transportation systems.

Future Plans: Plans are to make extensive measurements of the static pressures on the Comanche fuselage in the presence of the flow field of the Comanche anhedral tip rotor. DGV measurements will be added to the test instrumentation suite for the next test planned in FY02.

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STABILITY BOUNDARIES ESTABLISHED FOR BASELINE CONFIGURATION OF WRATS TILTROTOR MODEL

Mark W. Nixon

Objective: The objective of this test was to evaluate the stability characteristics of the baseline Wing and Rotor Aeroelastic Testing System (WRATS) tiltrotor model.

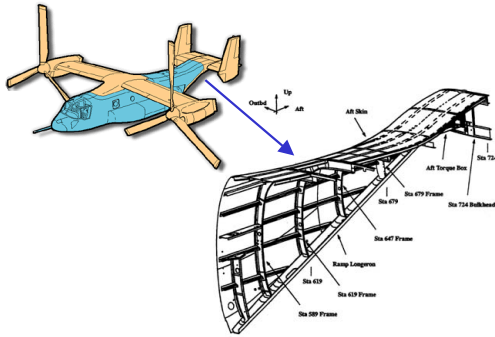
Approach: WRATS, a semispan testbed developed from the former V-22 1/5-scale aeroelastic tiltrotor model, was designed and fabricated by BHTI. The baseline model is currently on loan from the Navy to the NASA LaRC and is maintained by the LaRC Aeroelasticity Branch which operates the Transonic Dynamic Tunnel (TDT). Based on the use of the WRATS model, an aggressive test program was developed to address tiltrotor aeroelastic research issues as identified by: 1) the NASA Short-Haul Civil Tiltrotor (SH-CT) Program; 2) U.S. rotorcraft industry with regard to the development of marketable tiltrotor technologies; and 3) the U.S. Army with regard to the development of high-speed rotorcraft capabilities. A key to improving marketability of current tiltrotor systems is to reduce noise and weight and to improve aerodynamic performance. Such reductions and improvements generally result in an associated detrimental impact on the loads, vibration, and aeroelastic stability of the vehicle. One opportunity for improving aerodynamic performance in the airplane flight mode is to reduce the wing thickness to chord ratio (t/c). The current V-22 wing thickness (23% t/c) is necessary to provide the stiffnesses required to avoid propeller whirl flutter at high speeds. A new wing design has been developed with structural characteristics tailored using composite materials such that a thinner wing (18% t/c) will have stability characteristics equal to or better than the current thicker wing. The thick wing design is accurately represented by the current baseline WRATS tiltrotor model while the thin wing design has been fabricated by BHTI as a modification for the WRATS model.

Accomplishments: During a recent test of the WRATS baseline model in the airplane mode (photo on figure) a significant amount of high-quality data was obtained. The plots presented on the right side of the figure represent propeller whirl flutter boundaries for each of two wing torsion frequencies (altered by replacement of a pylon/wing connection spring). Each frequency corresponds to a different configuration of the full-scale pylon/wing downstop-lock mechanism. The boundaries are presented as rotor speed as a function of airspeed. As the plots show, a difference in wing torsion frequency of only 0.2 Hertz produced a shift in the flutter boundary of about 30 rpm at constant airspeed, or equivalently, a shift of about 12 knots at constant rpm. Subcritical damping data (not shown) of the wing modes as a function of airspeed for each of the two design rpm's was also obtained during the test.

Significance: The baseline stability data is of fundamental importance for demonstrating acceptable stability margins of a thin composite wing design which has been developed based on analytical stability predictions. The airspeed/rpm stability boundary data from this test will be used in conjunction with data developed from a planned composite tailored wing test to determine if the current analytical design is suitable for flight testing. The subcritical damping data will be used to compare with and refine analytical predictions.

Plans: The composite tailored wing modification to the baseline tiltrotor model is to be tested in the next WRATS entry. The WRATS has been repaired and will be operational in late CY01.

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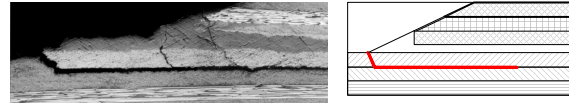


Post-buckling behavior drives weight in thin skin rotorcraft fuselage

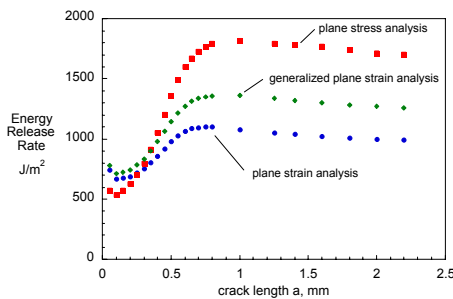
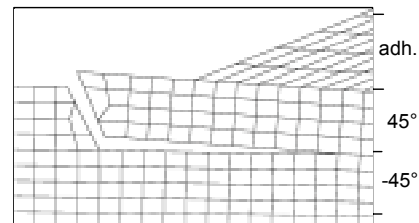
Buckling generates severe stresses on the bondline between skin and stiffeners

RAPID RAPID

Delamination B: skin 45/-45 interface



Matrix crack and delamination modeled as discrete discontinuity



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Composite Stringer Pull-off Failure Prediction

Dr. T. Kevin O'Brien

Relevant Milestone: Establish experimental and analytical methodology for composite stringer pull-off failure prediction. (RAPID Level 1 Milestone, due 4th Qtr FY01)

Shown: Computed energy release rates for delamination growing in top skin ply interface using different 2D assumptions

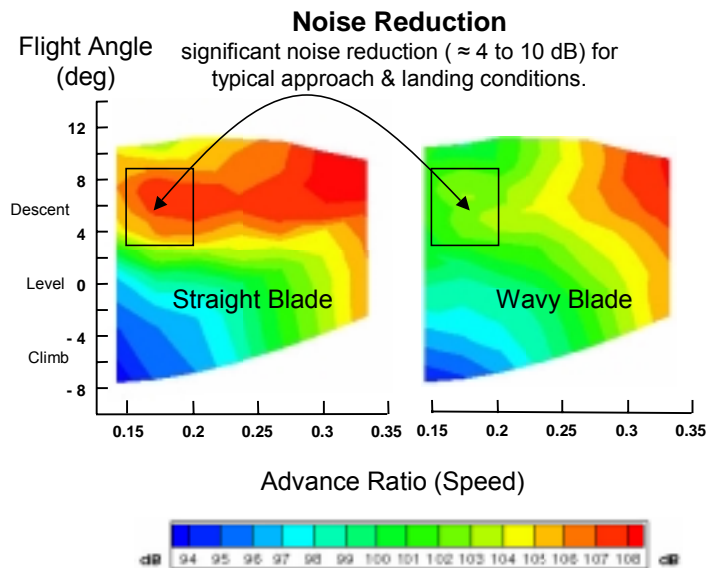
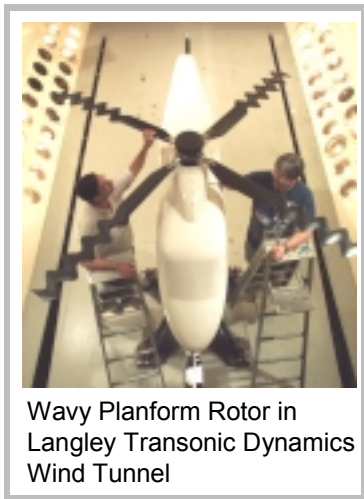
Accomplishments

- Rotorcraft fuselage consist of very thin composite skins reinforced with adhesive bonded stringers. Unlike fixed wing fuselage structure, these thin rotorcraft fuselage skins are allowed to buckle under repeated loading, resulting in a separation of the reinforcing stringers from the fuselage due to a combination of matrix cracking and delamination in the skin or stiffener flange.
- Two-dimensional (2D) finite element analyses of tension and bending specimens were performed substituting the standard 2D plane stress and 2D plane strain elements in the model along with a special 2D generalized plane strain element. Generalized plane strain elements are typically used to model a section of a long structure that is free to expand axially or is subjected to axial loading. Current models included matrix cracks and delaminations as observed in the static skin/flange tension and bending tests.
- Computed energy release rates were compared for all three types of 2D elements. As shown in the figure, results obtained from the generalized plane strain model fall between the upper and lower limits from the 2D plane stress and 2D plane strain elements. However, the different types of elements may yield results that differ by as much as 40%. Because 3D models are too large and slow for use in design studies, a 2D approach is desired. However, In order to determine which 2D assumption is most accurate for these types of problems, 3D models are needed.

Future Plans: A 3D finite element analysis will be developed to predict the damage observed in these skin/stringer pull-off specimens typical of rotorcraft fuselage constructions and determine the most accurate 2D approach for design trade off studies.

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Wavy Planform Rotor Reduces Noise by 4 to 10 db!



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Low Noise Planform

Thomas F. Brooks and Earl R. Booth

Relevant Milestone: Low Noise Rotor (SILNT #2 due Sep 00)

Shown: Wavy planform rotor. Noise levels of wavy rotor noise compared to baseline (straight) rotor.

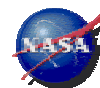
Accomplishment / Relationship to Milestone and ETO:

- The Wavy Planform Rotor (Patent Disclosure LAR16084-1, Brooks) was tested and compared with a rectangular planform, NACA 0012, linear twist blade set. This test completes the program milestone and is a major step toward the goal of the SILNT project to demonstrate new methods of rotor noise reduction.
- Acoustic measurements in the hard-walled reverberant wind tunnel test section employed sound power measurement techniques calibrated to determine noise levels but not noise directivity. Significant noise reductions of 4 to 10 dB were found for conditions dominated by blade-vortex interaction (BVI) noise, which is the biggest source of noise during approach and landing of helicopters. Beneficial noise reductions were also found in low and high frequency ranges which are significant in other flight regimes.
- This technology is a major step in providing community-friendly rotorcraft.

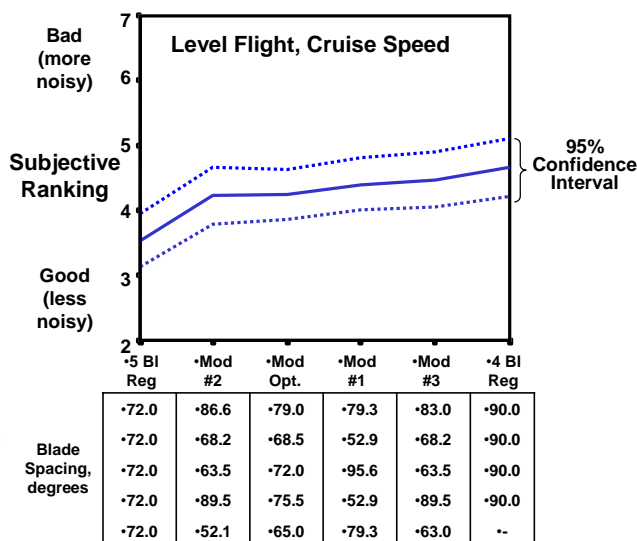
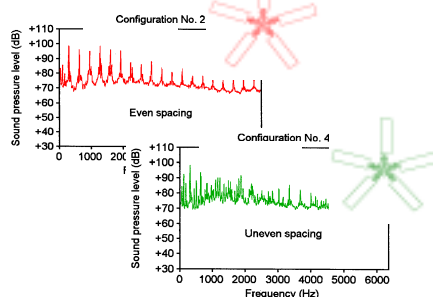
Future Plans: Continue data analysis is required to completely define the performance benefits. Technology will be transferred to industry, with proposal for cooperative agreement to refine rotor-blade design followed by testing.

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Modulated Blade Spacing for Helicopter Main Rotors



Preliminary Results of Psychoacoustic Test



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Modulated Blade Spacing for Helicopter Main Rotors Preliminary Results of Psychoacoustic Test

Brenda Sullivan, Bryan Edwards, and Earl R. Booth

Relevant Milestone: Assess the feasibility of multiple radical rotor noise & vibration reduction concepts.

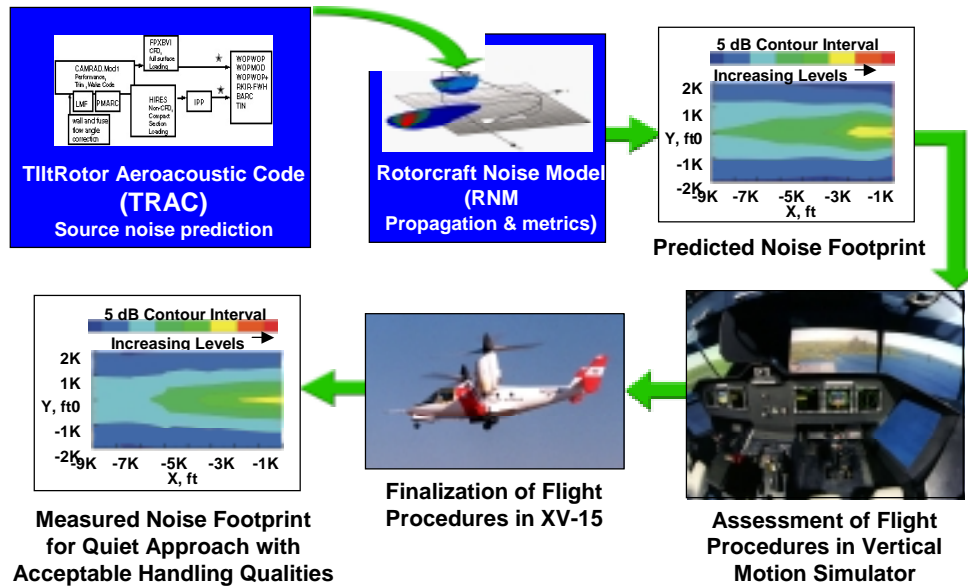
Shown: Photograph of subjects in psychoacoustic testing facility, a sketch of the modulated blade concepts and the effect uneven blade spacing on rotor spectra, and a plot of the subjective rating for the six configurations tested.

Accomplishment/Relationship to Milestone and ETG:

- A subjective test was conducted June 18-26 at the NASA-Langley psychoacoustic testing facility in which the simulated sounds of modulated and evenly-spaced rotors were played to a group of listeners.
- Six rotor configuration sound simulations were tested. The 4-blade regular spacing was based on the Bell Model 427 helicopter. The 5-blade main rotor with regular spacing was designed to approximate the performance of the 427, but at reduced tip speed. Four modulated rotors – one with “optimum” spacing and three alternate configurations – were derived from the 5 bladed regular spacing rotor.
- The sounds were played to 2 subjects at a time, with care being taken in the speaker selection and placement to ensure that the sounds were identical for each subject. A total of 40 subjects participated. For each rotor configuration, the listeners were asked to evaluate the full overflight sounds in terms of noisiness on a scale of 1 to 10.
- The test results are now being compiled. Preliminary results indicate little to no “annoyance” benefit for the modulated blade spacing. For the level flight condition shown, the subjects preferred the sound of the 5-blade regular spaced rotor over any of the modulated ones. All the modulated rotors and the 4-blade regular spaced were judged more annoying than the 5-blade regular.
- A preliminary conclusion is that modulated blade spacing is not a promising design feature to reduce the annoyance for main rotors, although reduced tip speed does hold much promise for evenly spaced main rotors.

Future Plans: Look at more random spacing between blades to determine if the beating effect seen was caused by blade spacing similarities

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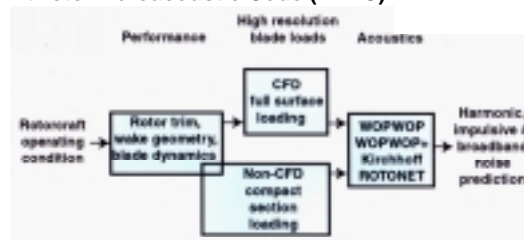
TiltRotor Aeroacoustic Code (TRAC) Development and Validation



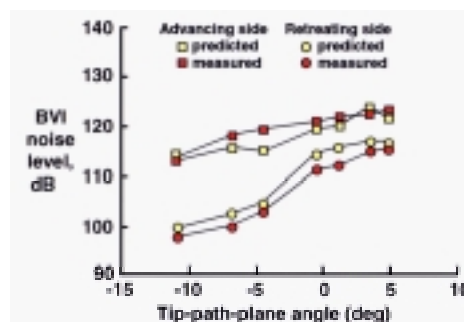
NASA/Army Bell Tiltrotor Aeroacoustic Test
15% scale model rotor in 14- by 22- foot W.T.



TiltRotor Aeroacoustic Code (TRAC)



Measured and Predicted BVI Noise Maximums



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TiltRotor Aeroacoustic Code (TRAC) Development and Validation

Casey Burley, Doug Boyd, Tom Brooks

Goal: Develop full vehicle noise modeling capability and validate with measurement with wind tunnel and flight testing.

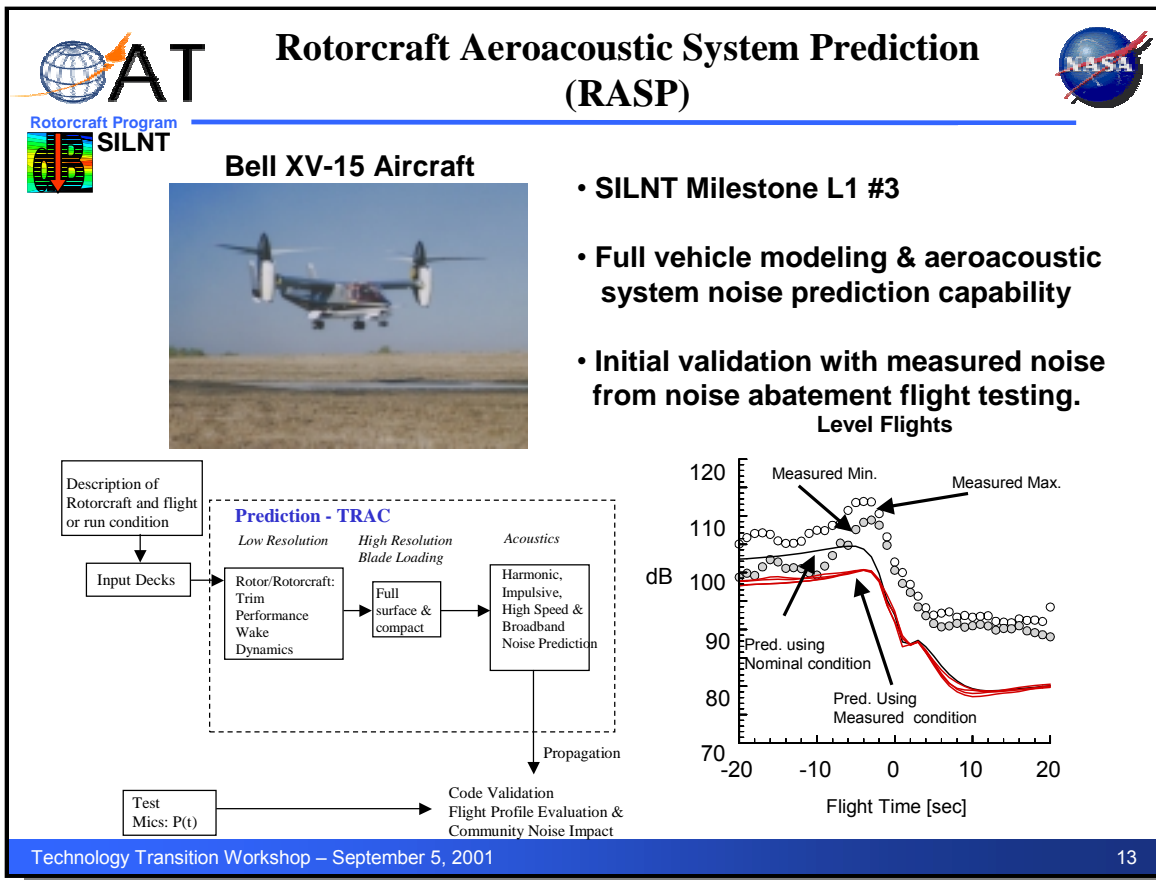
Shown: The NASA/Army Bell Tiltrotor Aeroacoustic Test 15% scale model rotor in 14- by 22- foot W.T. General flow and contents of the TRAC system. Example validation results.

Accomplishments: TRAC proprotor and rotor validation performed using Bo105, JVX, TRAM and XV-15 test data. The combined predictions of harmonic/BVI noise and broadband BWI and Self noise represent the first 'complete' main rotor-noise spectra prediction.

Plans: TRAC was a project of the SHCT Program and will be transitioned to the Rotorcraft Aeroacoustic System Prediction (RASP) code for continued flight noise prediction and system Analysis. This effort will include the improvement or inclusion of:

- improved source noise modeling
- rotor wake definitio
- rotor/Body Interactions
- Maneuvers

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Rotorcraft Aeroacoustic System Prediction (RASP) Development

C. L. Burley, T. F. Brooks, D. D. Boyd Jr., D. A. Conner

Relevant Milestones SILNT L1 :

#4 Validated capabilities for noise prediction, modeling, and reduction for rotorcraft.

#3 Develop full vehicle noise modeling capability & validate with measurement from noise abatement flight testing.

Shown: Initial flight predictions using RASP and comparison with measured flight data from an XV-15 rotorcraft during steady level flight and descent conditions .

Accomplishment/Relationship to Milestone:

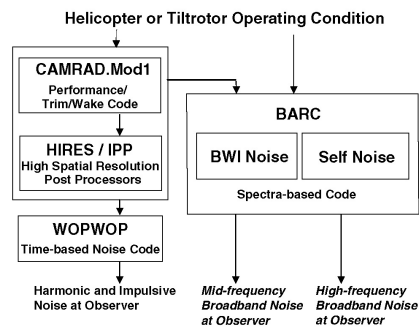
- The goal of the SILNT program is to provide analytical methods, advanced technologies and operational procedures that will improve ride quality, community and passenger acceptance by reduction of rotorcraft system noise and vibration.
- The Rotorcraft Aeroacoustic System Prediction (RASP) was utilized in predicting the noise on the ground during a steady level flight and descent conditions. Sensitivity of noise prediction to vehicle orientation, vehicle flight speed and descent rate were examined. Details of acoustic time histories were found to be sensitive, whereas integrated metrics were insensitive to the parameters considered.
- Comparison repeated measured flight acoustics found variability in flight condition and vehicle orientation as a function of flight time. Measurements were found to be within the expected range of repeatability for flight testing. However, variability found in measured flight condition and vehicle orientation parameters were found to have a significant effect on the measured acoustic time histories. A much less effect was found in the integrated noise metrics.

Plans: Perform comprehensive comparison of measured and predicted flight acoustics for XV-15 as well with available helicopter flight data. Enhance prediction capability for maneuver flight conditions in order to predict noise during flight abatement procedures.

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Prediction Code Elements



- **SILNT Milestone L1 #4**
- **Prediction of complete main rotor noise spectra (broadband + BVI noise)**
- **Validated with measured data for range of conditions (climb to steep descent)**

Measured and Predicted Noise Spectra
(descent condition, advancing side microphone)

Advanced Rotorcraft Aeroacoustic Modeling (ARAM) Development Project

C. L. Burley, T. F. Brooks, D. D. Boyd Jr.

Relevant Milestones SILNT L1 :

#4 Develop and validate advanced, computational methods for broadband noise prediction.

#1 Validate prediction of main rotor noise by comparison with measured helicopter noise footprints.

Shown: Schematic of BARC and prediction of the complete noise spectrum and comparison with measurement from a Bo105 40% scale main rotor.

Accomplishment/Relationship to Milestone:

- The goal of the SILNT program is to provide analytical methods, advanced technologies and operational procedures that will improve ride quality, community and passenger acceptance by reduction of rotorcraft system noise and vibration.
- The Broadband Rotor Aeroacoustic Code (BARC) was developed and validated with acoustic data obtained from a Bo105 model scale main rotor for conditions ranging from steep descent to climb. BARC predicts and combines the broadband noise sources of Blade Wake Interactions (BWI) noise and blade Self noise.
- The first predictions of complete noise spectra were made and compared to measured data from a scale model main rotor. The broadband noise predictions, along with those of harmonic and impulsive Blade-Vortex Interaction (BVI) noise predictions demonstrated a significant advance in predictive capability for main rotor noise.
- In a complimentary program conducted under the NASA Aviation System Capacity Program, the tiltrotor rotor aeroacoustic code (TRAC) was developed and validated. Prediction validation was performed for model and flight rotorcraft (tiltrotor and helicopter). Initial comparisons with flight data were performed and compared well.

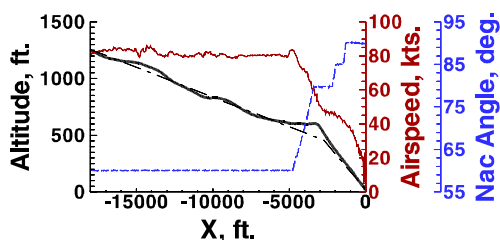
Plans: Completion BARC development for flight comparison. Perform comprehensive comparison of predicted and measured flight footprints for entire flight regime from climb to descent.

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Bell XV-15 Aircraft

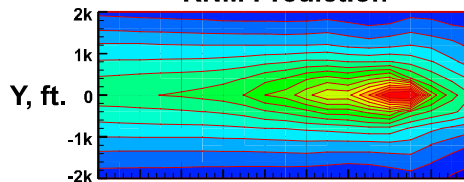


Approach Profile

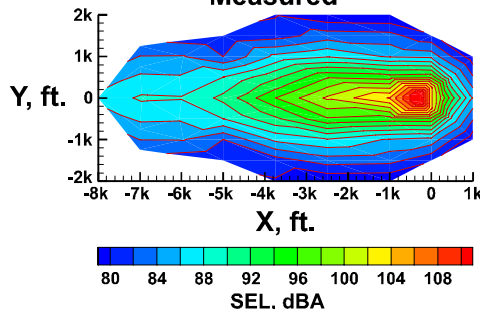


Noise Footprints

RNM Prediction



Measured



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RNM Prediction Comparison with XV-15 Measured Footprint

David A. Conner

Relevant Milestone: SILNT3 – Develop full vehicle noise modeling capability and validate using measured noise footprints obtained from noise abatement flight testing; and SILNT4 – Validate capabilities for noise prediction, modeling, and reduction for rotorcraft.

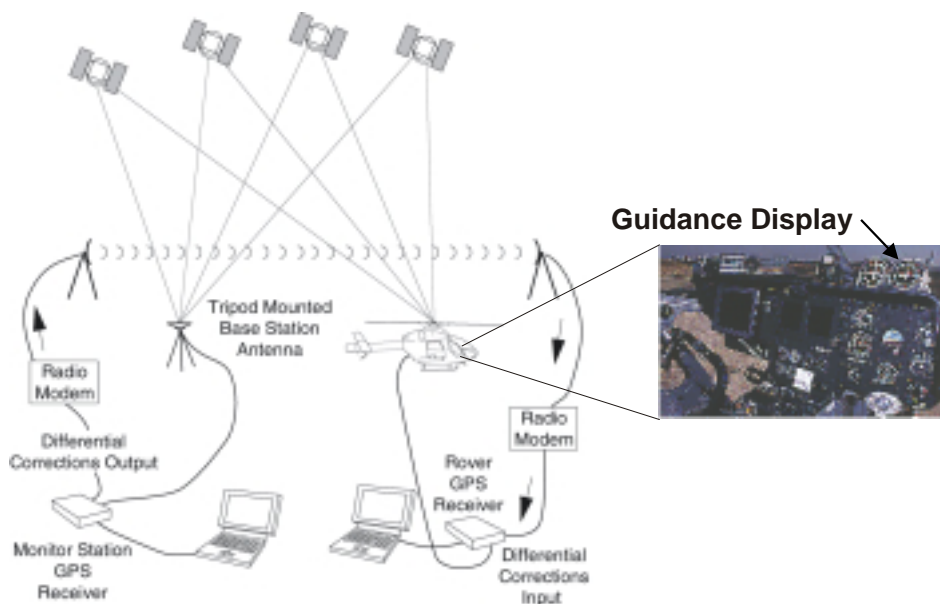
Shown: Photo of test vehicle, graphic of approach profile, measured noise footprint, and RNM predicted noise footprint.

Accomplishment/Relationship to Milestone and ETG:

- Measured XV-15 noise footprints have been compared to noise footprints predicted by the Rotorcraft Noise Model (RNM) for the purpose of validation of RNM.
- The example comparison shown was for a complex, multi-segmented, decelerating approach, including nacelle angle changes.
- The example comparison shows good agreement between the measured and predicted footprints. Similar results were found for several other XV-15, V-22 and SP-412 comparisons.

Plans: RNM will be further validated for additional flight conditions and other vehicles using both multiple data bases and aeroacoustic predictions. Enhancements to RNM are planned to (1) improve low incidence angle predictions, (2) model non-steady state flight conditions (accelerations, turns, etc.) and (3) account for propagation effects in an inner-city setting where reflections off of buildings can significantly alter the noise footprints, thus providing a more robust prediction capability.

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DGPS Tracking and Guidance System

David A. Conner

Relevant Milestone:

- SILNT3 – Develop full vehicle noise modeling capability and validate using measured noise footprints obtained from noise abatement flight testing.
- SILNT4 – Validate capabilities for noise prediction, modeling, and reduction for rotorcraft.

Shown: Sketch of DGPS system concept with photograph of a guidance display attached to top of instrument panel

Accomplishment/Relationship to Milestone and ETG:

- The DGPS tracking system will provide accurate time space position information relative to the ground-based microphone array. In addition, the pilot guidance system will improve flyover precision, thereby reducing test costs.
- Boeing-Mesa was awarded a contract to design and build the system and deliver it to NASA Langley. All system designs have been completed, all instrumentation has been procured, and all software has been written. System integration is nearly complete.

Plans: Customer acceptance demonstration flight test is planned to be conducted at UTSI, Tullahoma, Tennessee during 3rd week of September 2001. Upon acceptance, system will be delivered to NASA Langley. System will provide a valuable tool that will be utilized in future acoustic flight tests.

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HART II Test



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HART II Test

Casey L. Burley, Tom F. Brooks

Goal: Develop and validate rotor wake and acoustic codes to advance systems noise prediction capabilities

Task Benefit/Payoffs:

- Provide comprehensive database for source noise model development
- Improved prediction codes for quiet rotor design and low noise operation development

Task Deliverables:

- Comprehensive benchmark database
- Advanced prediction codes: LMF for rotor wake, and BARC for broadband and BVI noise

Approach:

- Conduct HART II in DNW
- Obtain 3-C PIV rotor wake measurements, acoustics (broadband and BVI), unsteady airloads and blade motion
- Theoretical and code development for wake, unsteady airloads and acoustic modeling

Partners:

- NASA, DLR, AFDD, ONERA, DNW
- Virginia Polytechnic Institute., Jolly Development Corporation, Florida State University

Customers: U.S. Rotorcraft industry, government, U.S. Military

Plans: Conduct the HART II test in late September. Analyze and publish test results in FY02. Validate prediction codes using test data.

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Langley Task Status Summary



Tasks	Funding Source	Status	Continuation actions
RAPID			
Active Twist Rotor (Joint with SILNT)	NASA RC/Army	V1 Test Complete	
Projection Moire Interferometry	NASA RC	Fielded	
Wing RotorAeroelastic Testing System	NASA RC/Army	Repaired	
Stringer Pull-off Prediction	NASA RC/Army	On-going	
SILNT			
Low Noise Planform	NASA RC	Complete	
Modulated Blade Spacing	NASA RC	Complete	
Development of Noise Abatement Procedures	NASA RC/SHCT/Army	On-going	
TiltRotor Aeroacoustic Code	NASA RC/SHCT/Army	Complete	
Rotorcraft Aeroacoustic System Prediction	NASA RC	On-going	
Advanced Rotor Aeroacoustic Modeling	NASA RC	On-going	
Rotorcraft Noise Model	NASA RC/SHCT/Army	V1 Fielded	
DGPS Tracking and Guidance System	NASA RC/SHCT/Army	Near Delivery	
HART II Test	NASA RC/SHCT	Nearly Complete	